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Models 5611 and 5612

User's Manual

Multipass Cell

Technology licensed from Aerodyne Research, Inc.
(Patent #5,291,265)

Warranty

New Focus, Inc. guarantees its products to be free of defects for one year from the date of shipment. This is in lieu of all other guarantees, expressed or implied, and does not cover incidental or consequential loss.

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Getting Started

Your multipass cell was shipped aligned to the standard 182-pass configuration (see Fig. 7, pg. 25) and is ready to use. To familiarize yourself with the operation of the multipass cell, you should begin by coupling a visible laser into the cell. A standard low-power He-Ne laser works well for this.

Couple light into the cell in the horizontal plane so that the input beam passes through the hole in the front mirror and hits the back mirror close to its edge. Light enters and exits the cell through the front window assembly. The input and output beams travel in the horizontal plane, cross at the front mirror surface, and make an angle of 3 to 6 degrees with respect to the cell axis.

It is helpful if the input beam is focused to a waist at roughly the center of the cell (a 25- to 75-cm focal length lens should work well). The output beam will exit the cell in the horizontal plane. If the output beam does not appear or is clipped, some slight adjustments to the cell position and the input beam angle may be necessary.

Note: Aligning the mirrors in the multipass cell is a complicated and potentially tricky procedure. This manual contains detailed operation and alignment instructions. Be sure to read through the manual before disassembling or realigning the multipass cell.

Introduction

The New Focus multipass cell design employs a patented technology (Patent #5,291,265, licensed from Aerodyne Research, Inc.) that causes the beam to fill the absorption volume more completely than in conventional multipass cells. The heart of this technology is the use of concave mirrors with a small amount of astigmatism. These astigmatic mirrors produce beam spots on the mirror surfaces which form a Lissajous' pattern. This is in contrast to the elliptical patterns produced by conventional multipass cells. The astigmatic mirrors enable more passes in a given volume, resulting in a smaller cell volume for a given optical path length.

The multipass cells come in two sizes: the Model 5611 has a 36-meter optical path length in a 0.3-liter cell and the Model 5612 has a 100-meter path length in a 3.2-liter cell. Light enters and exits the multipass cell through the front window assembly and, in the standard configuration, makes 182 passes between the mirrors.

The mirrors are made from nickel-plated aluminum substrates with a protected silver coating. The reflectivity of the mirrors from 3 to 10 µm is 99% or greater. Cell throughput can be estimated using the expression R^N, where R is the mirror reflectivity and N is the number of mirror reflections. In the standard 182-pass arrangement, the beam reflects off the mirrors 181 times. So, from 3 to 10 µm the throughput is $(0.99)^{181} = 16\%$. In the 1 to 3 µm wavelength range, the mirror reflectivity is about 98%, corresponding to a throughput of 2.6%.

Measurements can be performed from atmospheric pressure down to 1 torr. The cell is equipped with one 1/4-inch and two 1/2-inch fittings for flowing gas through the cell. The cell can also be sealed to perform static measurements involving a limited sample size. Note that the multipass cell is not intended for operation above atmospheric pressure. The back plate of the cell has a safety relief valve which will open if the cell pressure rises above 5 psi.

The multipass cell is shipped with the mirrors aligned to the standard 182-pass configuration. If necessary, the cell can be dismantled for cleaning and realignment. The front mirror is fixed in place, and the back mirror can be tilted, rotated, and translated for all necessary alignment adjustments. Instructions for operation and alignment of the multipass cell are given in the sections that follow. Please read through these sections before adjusting the orientation of the back mirror.

Background & Theory

This section presents a brief background on the multipass cell and an overview of the theory used in the cell's design and analysis. For more details about the design, analysis and use of multipass cells, refer to J. B. McManus, P. L. Kebabian, and M. S. Zahniser, "Astigmatic mirror multipass absorption cells for long-path-length spectroscopy," *Applied Optics*, Vol. 34, No. 18, pages 3336-3348, 20 June 1995.

The New Focus multipass cell is a variation on the Herriot cell which employs two spherical mirrors separated by nearly their radius of curvature. This cell produces a circular or elliptical beam spot pattern on the mirrors. A modified Herriot cell that employs astigmatic mirrors will yield a longer optical path length for a given cell volume. However, achieving proper alignment of this sort of cell requires that the astigmatic mirrors be manufactured with extremely high precision.

The New Focus multipass cell employs astigmatic mirrors along with a technique that eliminates the need for such high manufacturing tolerances. By adjusting the twist angle between the front and back mirrors, one can compensate for variations in the mirror radii of curvature resulting from the relaxed mirror tolerances. This innovation was developed and patented by Aerodyne Research, Inc.

The multipass cell employs astigmatic, or toroidal, mirrors. That is, along the two orthogonal axes, the mirrors have radii of curvature that differ by

about 10%. In the multipass cell the mirrors are separated by nearly their radius of curvature, and an optical beam is coupled into the cell through a hole in the front mirror. The beam enters the cell in the horizontal plane at an angle to the axis of the cell and then bounces back and forth a number of times between the mirrors. If the cell is aligned correctly, the beam will travel along a reentrant path which closes upon itself at the coupling hole after a finite number of passes. Then, the beam exits the cell through the original coupling hole.

The astigmatic mirrors of the multipass cell cause the beam to travel in a path such that the beam spots on the mirrors trace out a Lissajous' pattern. In other words, the beam spots trace out a pattern that is sinusoidal in x and y, but has different frequencies in the two directions. For a reentrant path, the *x*-*y* coordinates of the spot pattern on the mirrors are given by:

$$x_i = X_o \sin\left(i\Theta_x\right) \quad \text{and} \quad y_i = Y_o \sin\left(i\Theta_y\right),$$

where

$$\Theta_x = \pi M_x / N \qquad \text{and} \qquad \Theta_y = \pi M_y / N .$$

X_0 and Y_0 define the size of the spot pattern on the mirror. N is the number of passes through the cell, and N is even so the beam enters and exits the cell through the same mirror. The i parameter varies from 1 to N and indicates the order of appearance of each spot on the mirrors. M_x and M_y are integers that determine the shape of the beam spot pattern; these parameters are related to the mirror radii of

curvature and the separation between the mirrors. The above expression is approximate because it does not account for the twist angle between the mirrors or for variations in the mirror radii. However, the spot patterns resulting from these expressions are still very useful for analyzing and aligning the multipass cell.

There are a large number of available spot patterns, as given by the many possible combinations of $\{N, M_x, M_y\}$. Choosing these parameters and a base length for the cell defines the spot pattern and results in design values for the mirror radii. The spot patterns are all contained within a rectangular boundary, but each spot pattern has its own unique shape and appearance. In addition, each spot pattern has a different distance of closest approach of spots to the coupling hole and a different sensitivity to mirror misalignment.

Choosing a good pattern involves finding a design with a long path length (large N), a good separation and distribution of the beam spots (to reduce interference effects), and a relative insensitivity of the spot pattern to mirror misalignment.

The standard 91-spot pattern for the multipass cell, which has the parameters $\{N=182, M_x=80, M_y=76\}$, was chosen to optimize the above considerations. This arrangement gives 182 passes between the mirrors. The theoretical 91-spot pattern for this arrangement is plotted in Figure 1. In the figure the diameter of each spot is proportional to beam intensity to simulate the decreasing intensity of the beam as it reflects off the mirrors.

Fig. 1

Theoretical beam spot pattern for the standard 182-pass configuration.

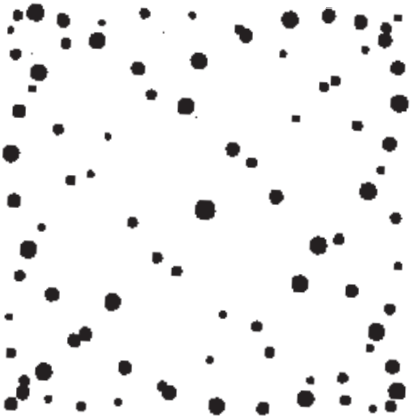


Fig. 2

Mechanical drawing of the model 5611 36-meter cell.

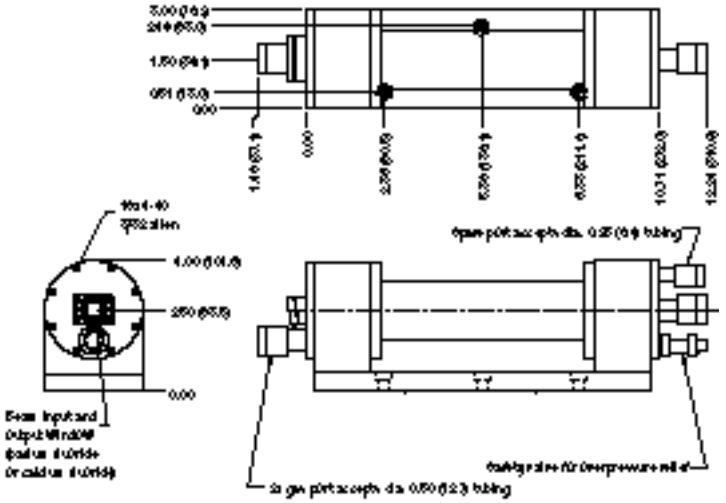
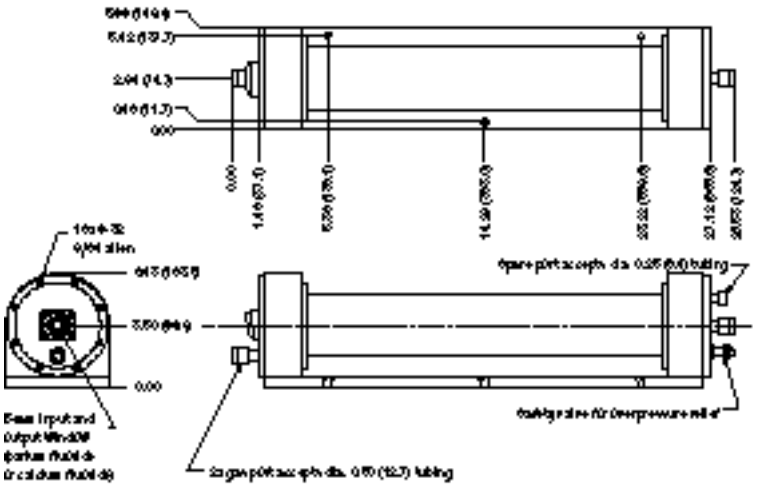


Fig. 3

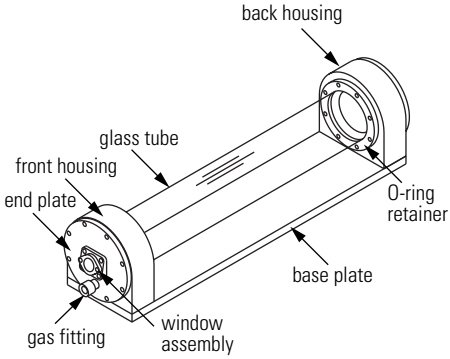
Mechanical drawing of the model 5612 100-meter cell.



Description

Fig. 4

Schematic drawing of the multipass cell.



This section details the parts that make up the multipass cell and how they fit together. The Models 5611 and 5612 multipass cells consist of the same type of parts; the 100-meter cell is just a scaled-up version of the 36-meter cell. Note that the multipass cell is put together with an assortment of cap screws with English threads. A set of ball drivers is provided with each multipass cell to allow the cell to be dismantled and aligned, if necessary.

The multipass cell is divided into six main parts: base plate, glass tube, two housings, and two mirrors.

Base Plate

The base plate is a piece of anodized aluminum with three slots for mounting on optical tables with 1-inch or 25-mm hole spacing. At either end of the base plate is a housing attached to the base plate by two 1/4-20 cap screws. In addition, two alignment pins fit into holes in the bottom of the housings. The pins allow the housings to be removed and reattached to the base plate without upsetting the mirror alignment.

Glass Tube

The glass tube is made of borosilicate glass, and the tube is sealed to the housings with an O-ring that is held in place by an anodized aluminum O-ring retainer. All the O-rings used in the multipass cell are made of Viton® fluoroelastomer. The O-ring retainer is attached to the housing with eight screws. When removing the housing from the base plate, the O-ring retainer screws should first be loosened to prevent the glass tube from cracking.

(Viton is a registered trademark of DuPont Dow Elastomers.)

Housings

The two housings are made of nickel-coated aluminum. Aside from the aluminum mirrors and the housings, the remaining metal parts inside the cell are made of stainless steel.

Each housing has a circular end plate attached to it with 8 screws. An O-ring seated in the housing forms a seal between the housing and the plate.

The front and back plates have a total of three couplings for a variety of uses such as flowing gas through the cell or monitoring the cell pressure.

The two larger couplings are for 1/2-inch diameter tubing, and the single smaller coupling is for 1/4-inch diameter tubing. The couplings have internal O-ring seals which compress on the tube by finger-tightening the knurled nut. The couplings are equipped with solid plugs to block them when they are not in use.

The multipass cell is not intended to be operated above ambient air pressure. The back plate of the cell is equipped with a safety relief valve to prevent the cell from being accidentally over-pressurized. This valve will open if the cell pressure rises above the outside air pressure by 5 psi. The accessories shipped with the cell include a hose connector which can be attached to the relief valve, allowing the gas in the cell to be safely vented through tubing. This tubing should have an inner diameter of 1/4 inch (6.4 mm).

The window assembly attached to the front plate consists of two stainless steel pieces and the window, which is a calcium fluoride or a barium fluoride disk. The window housing piece with the two screws holds the window in place, and an O-ring makes a seal between the window and the second piece of the window housing. **Note:** Do not over-tighten the two screws that hold the window in place. Tighten them just enough so that the O-ring makes a good seal with the window. Over-tightening the two screws could cause the window to break.

Mirrors

The mirrors are made of a nickel-plated aluminum substrate that is polished into the desired toroidal shape. Then, a protected silver coating is deposited onto this surface. This silver coating has optimal reflectivity from 3 to 10 µm and can withstand cw powers up to 1 kW/cm^2. The flat surface on the edge of the mirror is approximately aligned with one of the mirror's toroidal axes.

The mirrors should be handled and cleaned with extreme care. Despite the protective dielectric coating, the mirror surface can be scratched easily. The mirrors should be cleaned by non-contact methods such as flowing methanol or acetone and blowing with a stream of filtered air or nitrogen. Use lens cleaning paper with caution as it can scratch the mirror surface.

The mirrors are mounted inside the housings and are accessed by removing the circular plates at either end of the multipass cell. The front mirror is fixed in place and has no alignment adjustments. The hole through the center is for coupling light into and out of the cell. The diameter of this hole is 0.10-inch (2.5-mm) for the Model 5611 and 0.17-inch (4.3-mm) for the Model 5612. The front mirror should be oriented so that the flat surface faces upward.

The front mirror is mounted to a triangular plate with three screws. This triangular plate is in turn mounted to the housing with three more screws.

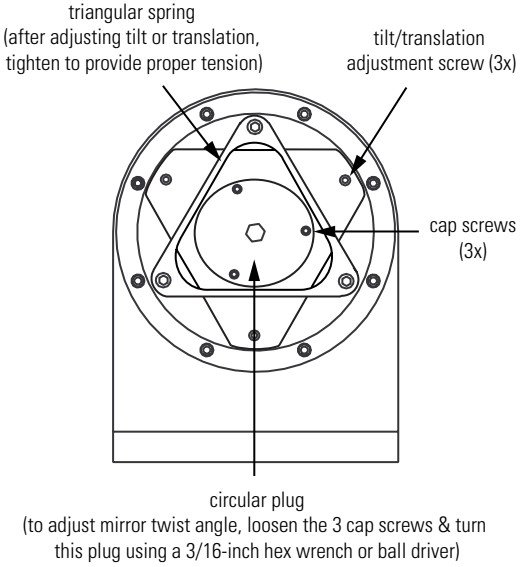
The front mirror can be removed from the cell by removing the triangular plate to which it is attached. Be careful not to scratch or touch the mirror surface when removing or re-installing it.

All adjustments to the multipass cell alignment are made with the back mirror assembly (see Fig. 5, page 16). The back mirror assembly can be tilted, translated and rotated. The mirror is mounted with three screws to a circular plug that is fitted through a triangular plate. This triangular plate is held in place by a triangular spring attached to the housing with three screws. The spring provides tension to hold the mirror assembly in place. The position of the triangular plate is set by three set screws that are seated in grooves in the housing. By turning all three set screws the same amount, the mirror can be translated. Note that as the mirror is translated, the three screws holding the triangular spring should be adjusted to maintain a light spring tension on the mirror assembly. Later, when the cell is aligned, these screws can be tightened to lock the back mirror assembly in place.

Finally, when the three screws that attach the mirror to the circular plug are loosened, the plug can be rotated. The plug has a hexagonal hole in its center where a ball driver can be inserted to rotate the mirror. Rotating the back mirror allows adjustment of the twist angle between the front and back mirrors.

Fig. 5

Back end of multipass cell, shown with back plate removed.


triangular spring
(after adjusting tilt or translation,
tighten to provide proper tension)
tilt/translation
adjustment screw (3x)
cap screws
(3x)
circular plug
(to adjust mirror twist angle, loosen the 3 cap screws & turn
this plug using a 3/16-inch hex wrench or ball driver)

Safety

New Focus does not guarantee the suitability of the multipass cell for use with specific gases. However, the cell parts, as detailed in the previous section, are made of materials that are fairly robust and resistant to corrosion. Examples of gases that should be compatible with the multipass cell include CO, CO_2, NO, N_2O, NO_2, SO_2, O_2, and O_3.

The multipass cell can operate from 1 torr up to 760 torr (1 atm). The cell is not designed for use above atmospheric pressure.

To prevent the cell from being over-pressurized, the cell is equipped with a safety relief valve that will open if the internal cell pressure reaches 5 psi above the pressure outside the cell. If the gas used in the cell is corrosive or poisonous, the hose connector supplied with the cell should be attached to the relief valve, and 1/4-inch (6.4-mm) inner-diameter tubing should be attached to the hose connector. This tubing should be run to an exhaust location where the cell contents can be safely vented if the cell is accidentally over-pressurized.

The recommended operating temperature of the multipass cell is from 10 to 40 °C.

Operation

This section covers the basic set up and operation of the multipass cell. When the cell was shipped, the mirrors were aligned to the standard 182-pass configuration (with 91 beam spots on the back mirror and 90 spots on the front mirror). This section discusses how to align a laser beam into the cell, assuming that the mirrors in the cell are already aligned. If the cell requires alignment from scratch, refer also to the next section.

In general, the laser that is ultimately used with the multipass cell will not operate in the visible range. However, a visible laser, such as a 1-mW He-Ne laser, works best for performing the initial set up and alignment of the multipass cell. Once the cell is aligned with the visible beam and you are familiar with coupling light into the cell, you can then use the cell with the laser of interest.

Although the multipass cell will work with a collimated beam, it is recommended to use a slightly focused beam. Focusing the input beam makes it easier to see the beam spots on the mirrors and identify the beam spot pattern. The input beam should be focused to a waist at roughly the center of the cell. An f/40 or greater focal ratio is recommended, but the choice of lens focal length is not critical. For a typical He-Ne laser a lens with a focal length from 25 to 75 cm should work well. As an optical element, the cell functions as if the beam were reflected off the imaginary convex surface of the front mirror. Thus, sending a focusing beam into the cell results in a nearly collimated output beam.

The glass tube can be removed for initial alignment purposes. This eliminates confusing reflections and makes the beam spots easier to see. To remove the glass tube, the O-ring retainers must be loosened and then the housings must be momentarily detached from the base plate. (See Fig. 4, page 11.) Later, once the cell is aligned, the glass tube can be reinstalled.

For the Model 5611 36-meter multipass cell the input and output beam height is 2.5 inches (63.5 mm), and for the Model 5612 100-meter multipass cell the beam height is 3.5 inches (88.9 mm). Both input and output beams are in the horizontal plane and cross at the center of the coupling hole in the mirror. The input and output beams enter and exit the cell at an angle from the center line of the cell. Note that the beam can enter the cell from the right or from the left. For the Model 5611 cell the beams are at an angle of 5 to 6 degrees relative to the center line of the cell, and for the Model 5612 cell the beams are at an angle of 3 to 4 degrees. The input beam should be aligned so that the first spot on the back mirror hits the mirror near its edge and creates a spot pattern that fills the mirror. If the mirrors of the multipass cell are aligned correctly, then small adjustments to the position of the cell and to the pointing of the input beam should result in the appearance of the desired output beam.

When the multipass cell is aligned to the standard 182-pass configuration, the spot patterns on the mirrors should be similar to the patterns shown in Figure 7 on page 25. The beam can enter the cell

from the left or the right, relative to the axis of the cell. The spot patterns in Figure 7 were generated assuming the beam enters the cell from the right (as you face the input window). If the beam enters from the left, the same patterns will appear, but they will be reflected about the center of the circle. Identifying the spot pattern can be somewhat tricky at first, but it becomes easier with a little practice.

The spot pattern may not precisely match the patterns shown in Figure 7 due to slight variations in the mirror radii of curvature. However, the characteristic features of the spot patterns in Figure 7 should still be preserved, and these features are the key to identifying the correct pattern. One notable feature is the two sets of three beam spots that appear above and below the input coupling hole (spots 24, 49, and 25 above and spots 66, 42, and 67 below). The position of these spots should be similar to that shown in Figure 7. In addition, the relative intensity of these spots should correspond to the numbers that label them (larger numbers indicate dimmer spots).

Working with a focused visible laser source in a darkened lab makes it easier to see the beam spots on the mirrors. Also, removing the back plate allows access to the tilting adjustments (see Fig. 5, page 16). Turning one of the tilt adjustment set screws back and forth by about an eighth-turn will cause the spot pattern to move on the mirror surface, making some of the dimmer spots easier to see.

If the output beam does not appear or is clipped by the mirror coupling hole, then the back mirror

might require slight alignment adjustments. The mirror tilt can be adjusted using the tilt/translation set screws to fine-tune the spot pattern. Before doing this, loosen the three screws that hold the triangular spring to reduce pressure on the set screw threads. To translate the mirror, turn each of the three set screws the same amount (about an eighth-turn at a time works well) and readjust the triangular spring tension, if necessary. Note: Do not turn any set screw more than 1/4-turn or the cell may become misaligned. For details on aligning the cell from scratch, refer to the next section.

The mirror twist angle can be adjusted by loosening the three cap screws that hold the back mirror and then rotating the circular plug (no more than a few degrees at a time). The mirror is designed so the flat surface on the edge faces approximately upward. The actual orientation for correct alignment varies from mirror to mirror due to variations in the manufacturing process. When the cell was aligned at New Focus to the 182-pass configuration, the circular plug and the triangular plate were scribed. When the cell is aligned properly, these scribes should be lined up.

Note that small changes to the separation and twist angle between the mirrors can cause a variety of nearly reentrant spot patterns to appear. And so, be careful when adjusting the back mirror orientation because it is easy to misalign the cell. If the multipass cell needs to be realigned from scratch, refer to the next section for detailed alignment instructions.

Alignment

The multipass cell is shipped from New Focus aligned to the standard 182-pass configuration. In case the cell needs to be aligned from scratch, this section presents an alignment procedure. Alignment of the cell the first few times can be a tricky procedure, but with practice alignment becomes straightforward. Some sort of measuring device (such as a caliper or a depth gauge) with accuracy of 0.001 inches (0.025 mm) is required to align the multipass cell. The glass tube should be removed from the cell before attempting alignment.

All adjustments to the multipass cell alignment are made with the back mirror assembly. (see Fig. 5, page 16). The mirror tilt is adjusted by turning the tilt/translation set screws individually, and the mirror can be translated by turning all three set screws by the same amount. Clockwise rotation moves the two mirrors apart, and counterclockwise rotation moves the two mirrors together. The three set screws have 80-pitch threads, meaning that one full rotation of the screw results in a translation of 1/80 inches (0.0125 in, or 0.318 mm). If the back mirror is translated, the screws that hold the triangular spring should be adjusted to maintain moderate tension on the back mirror. Finally, the back mirror can be rotated, or twisted, relative to the stationary front mirror. Rotation of the back mirror is accomplished by loosening the three cap screws that hold the mirror onto the circular plug. These three cap screws have spring washers so that they can be loosened and still maintain tension on the mirror. The mirror is rotated using a 3/16-inch hex wrench or ball driver.

The important alignment parameters are the mirror separation and the twist angle between the mirrors. The tilt of the back mirror is not a crucial alignment; it is used to fine-tune the spot pattern.

The flat surface at the edge of the mirrors is roughly aligned with one of the axes of the astigmatic mirror surface. The mirrors should be oriented so this surface is facing approximately upward. For the back mirror the scribe marked on the circular plug should be lined-up with the scribe on the triangular plate.

Confirming that the multipass cell is correctly aligned is best accomplished by recognizing the beam spot pattern on the mirrors. Counting the spots is generally quite difficult. Instead, one can identify the correct alignment by matching the spot pattern to the theoretical spot patterns given on pages 24 and 25. Within the spot patterns, one can usually identify characteristic sub-patterns of spots that help to confirm that the cell is correctly aligned.

There are two techniques for aligning the multipass cell. The first involves aligning the cell to a 90-pass spot pattern as a starting point. From there, the back mirror is translated a precise amount to reach the desired 182-pass configuration. Note that the 90-pass spot pattern is another arrangement that could also be useful for performing measurements. For the Model 5611 the 90-pass configuration gives an 18-meter path length, and for the Model 5612 the 90-pass configuration gives a 50-meter path length.

Fig. 6

Pattern of beam spots for the 90-pass configuration.

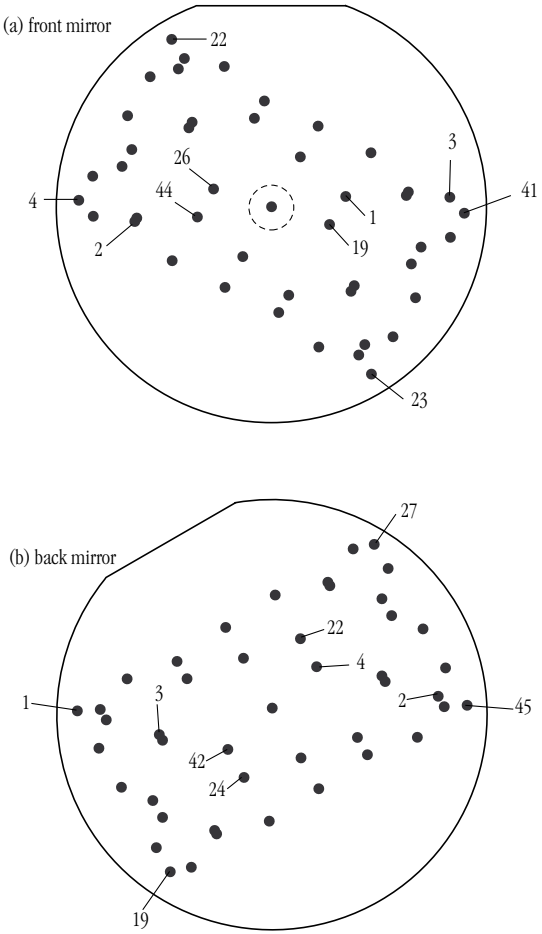
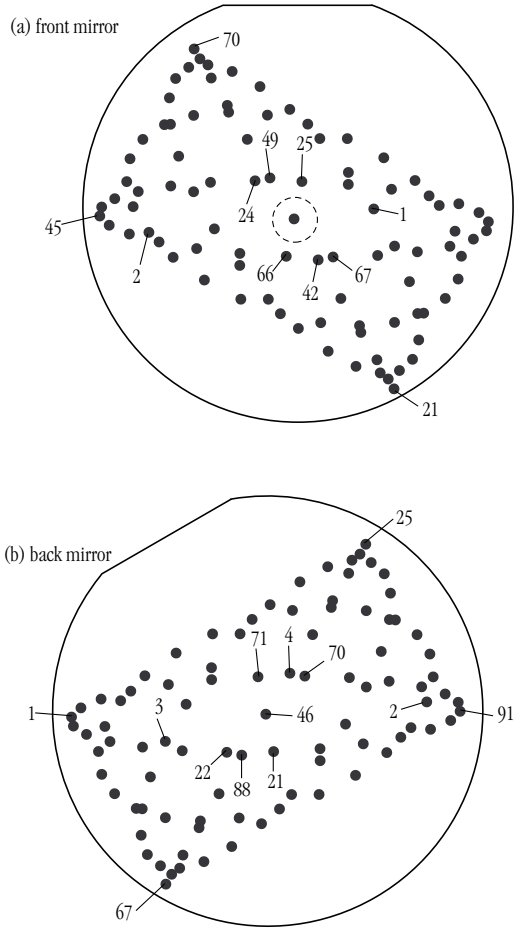


Fig. 7

Pattern of beam spots for the 182-pass configuration.



The second alignment technique involves locating the 182-pass configuration directly. This second technique is more difficult because the 182-pass configuration is a more difficult pattern to find. In the first technique, we use the 90-pass configuration as a relatively easy reference point to start from.

Figure 6 (page 24) shows the theoretical 45-beam spot pattern for the 90-pass configuration, and Figure 7 (page 25) shows the theoretical 91-beam spot pattern for the 182-pass configuration. The dashed circle in the center of the front mirror indicates the input/output coupling hole. The numbers that label some of the spots indicate the order in which the spots appear on the mirror.

Note that the spot patterns are circularly symmetric. Also, note that the first spot on the back mirror is always at the extreme edge of the pattern and sets the overall size of the spot pattern. The position of this first spot is determined by the angle of the input beam relative to the axis of the cell. The beam can enter the cell from the left or the right; the spot patterns in Figures 6 and 7 were made assuming the beam enters the cell from the right. If the beam enters from the left, the same patterns will result but they will be reflected about the center of the circle.

To align the mirrors remove the back plate and O-ring to access the back mirror tilt and translation adjustments. The alignment procedure involves measuring the distance from the end surface of the housing to the surface of the triangular plate. To locate the 90-pass configuration, set

this distance to the values written on page 31 by adjusting the three set screws. For the small multipass cell (Model 5611), the nominal distance is 0.250±0.010 inches (6.35±0.25 mm). For the large multipass cell (Model 5612), the nominal distance is 0.320±0.030 inches (8.13±0.76 mm). The tolerances indicate approximately how much the mirror position can be off by and still allow the correct spot pattern to appear.

Next, couple light into the cell. To confirm that the back mirror is not tilted, shine the beam straight through the input hole of the front mirror onto the center of the back mirror. Adjust the back mirror tilt until the reflected beam is centered on the input hole. Then, couple the light into the cell at an angle so that the first spot on the back mirror hits the back mirror close to its edge.

Loosen the three cap screws on the circular plug that holds the back mirror in place against the triangular plate. Rotate the back mirror with a 3/16-inch ball driver until the beam spot pattern corresponding to the 90-pass configuration appears (see Fig. 6, page 24).

With some practice and perhaps a few iterations, the 45-spot pattern corresponding to the 90-pass configuration should be located and identified, and the output beam should appear. If the output beam is clipped by the coupling hole, small translations and rotations of the back mirror will center the output beam through the coupling hole.

Finally, small adjustments to the tilt and translation of the back mirror, the mirror twist angle, and

the pointing of the input beam can be performed to fine tune the spot pattern.

Once the multipass cell is aligned to the 90-pass configuration, you are ready to translate the back mirror to reach the 182-pass configuration. As with the 90-pass configuration, the distance from the end of the housing to the triangular plate is used to locate the 182-pass configuration. Refer to the distance written on page 31 for your particular multipass cell. For the small multipass cell (Model 5611) the nominal distance is 0.395±0.005 inches (10.03±0.13 mm). For the large multipass cell (Model 5612) the nominal distance is 0.720±0.014 inches (18.29±0.36 mm).

If the cell is aligned to the 90-pass configuration, you can reach the 182-pass configuration by translating the back mirror toward the front mirror. For the small multipass cell (Model 5611), the back mirror should be translated by 0.145 inches (3.68 mm), or about 11.6 counterclockwise rotations of the three set screws. For the large multipass cell (Model 5612), the back mirror should be translated by 0.400 inches (10.16 mm), or about 32 counterclockwise rotations of the three set screws. The twist angle of the back mirror is the same to within one degree for both the 90- and 182-pass configurations.

Once the back mirror is translated into position, the 91-spot pattern shown in Fig. 7 (page 25) still may not appear or the output beam may be partially clipped by the coupling hole. To fine tune the alignment, the back mirror can be rotated, but not by more than a few degrees. The back mirror can also be tilted and translated slightly.

Admittedly, locating and identifying the 91-spot pattern is not trivial, but with practice it becomes easier. The spot pattern may not precisely match the patterns shown in Figure 7 due to variations in the mirror radii of curvature. However, the characteristic features of the spot patterns in Figure 7 should still be preserved. These features are the key to identifying the correct pattern. One notable feature is the two sets of three beam spots that appear above (spots 24, 49, and 25) and below (spots 66, 42, and 67) the input coupling hole. Another is the line of spots that runs from the top to the bottom of the spot pattern, beginning with spot 70 and ending with spot 21. And finally, note the circular clusters of spots on the left and right sides of the mirror.

Specifications

Model #	5611	5612
Path Length	36 m	100 m
# of Passes	182 passes	182 passes
Mirror Separation	20 cm	55 cm
Cell Volume	0.3 liters	3.2 liters
Gas Fittings	two 1/2" dia. and one 1/4" dia.	two 1/2" dia. and one 1/4" dia.
Pressure	1–760 Torr	1–760 Torr
Mirrors	protected silver coating	
Reflectivity (3–10 µm)	>99%	>99%
Reflectivity (1–3 µm)	>98%	>98%

Alignment Data

Model Number: _____

Serial Number: _____

Back mirror position (distance from the end surface of the housing to the surface of the triangular plate):

90-Pass Configuration: _____

182-Pass Configuration: _____

NEW FOCUS, Inc.
2630 Walsh Avenue
Santa Clara, CA 95051-0905
USA

Phone: (408) 980-8088
Fax: (408) 980-8883
Email: Contact@NewFocus.com